Instrument Catalog Object

An instrument catalog object will need to be completed for each instrument or collection of sensors used to acquire data on the Mars Polar Lander. For example, although it is not an instrument *per se*, an instrument catalog object will need to be written describing the collection of sensors on the Robotic Arm. If in doubt, please contact the PDS for assistance.

The following description of the instrument catalog object is taken from appendix B.4 of the PDS Standards Reference (available online at `http://pds.jpl.nasa.gov/stdrefnew/`). Due to the nature of the integrated archive that we will be producing for the Mars Polar Lander data, there are a few points that should be noted in addition to those in the formal PDS standards:

- When filling out the instrument catalog object, please **do not** quote directly from papers you have submitted or will submit to the Journal of Geophysical Research. This journal is strict about enforcing its copyrights and will not permit us to reproduce their papers on PDS CDs.
- Where it has any relevance to the data collected, the "Location" section (described below) should be included, since, like an earth-based instrument, we have a fixed location on the planet. However, check with the MVACS archiving team before writing your own text, since they may already have prepared a paragraph which you can use to fill this in.
- A common set of REFERENCE objects will be maintained by the MVACS archiving team for use by all of the instrument teams and PDS nodes. Before creating a new REFERENCE KEY ID and associated object, please check that they have not already created it.

The INSTRUMENT catalog object is used to submit information about an instrument to PDS. Instruments are typically associated with a particular spacecraft or earth based host, so the INSTRUMENT_HOST_ID keyword may identify either a valid SPACECRAFT_ID or EARTH_BASE_ID. The catalog object includes a textual description of the instrument and a sub-object for identifying reference information. A separate REFERENCE object will need to be completed for any new references not already part of the PDS catalog.

1) The INSTRUMENT INFORMATION catalog object provides a description of the instrument. The following paragraph headings and suggested contents are strongly recommended as the minimal set of information necessary to adequately describe an instrument. Additional headings may be appropriate for specific instruments and these also may be added here. Should any of the recommended headings *not* appear within a textual description, they will be considered not applicable to the data set.

    Instrument Overview
    A high-level description of the characteristics and properties of an instrument.

    Scientific Objectives
    The scientific objectives of data obtained from this instrument.

    Calibration
    Methods / procedures / schedules of instrument calibration. Calibration stability, parameters, etc.

    Operational Considerations
    Special circumstances or events that affect the instrument's ability to acquire high quality data (which are reflected in the archive product). Examples might be spacecraft charging, thruster firings, contamination from other instruments, air quality, temperatures, etc.

    Detectors
    General description of detector(s). Type of detector used. Sensitivity and noise levels. Detector fields of view, geometric factors, etc. Instrument / detector mounting descriptions (offset angles, pointing positions, etc.)

Electronics

Description of the instrument electronics and internal data processing (A-D converter).

Filters

Description of instrument filters and filter calibrations (filter type, center wavelength, min / max wavelength) if applicable.

Optics

Description of instrument optics (focal lengths, transmittance, diameter, resolution, t_number, etc.) if applicable.

Location

Latitude and longitude location, for earth based instruments.

Operational Modes

Description of instrument configurations for data acquisitions. Description of "modes" (scan, gain, etc.) of data acquisition and of measured parameter(s) and / or data sampling rates or schemes used in each mode.

Subsystems

Logical subsystems of the instrument. Description of each subsystem, how it's used, which "modes" make use of which subsystem, etc.

Measured Parameters

Description of what the instrument directly measures (particle counts, mag. Field components, radiance, current / voltage ratios, etc.) Description and definition of these measurements (min / max, noise levels, units, time interval between measurements, etc.)

(OTHER - Data Supplier provided):

Any other important information in additional headings as desired (e.g. Data Reduction, Data Compression, Time-Tagging, Diagnostics, etc.)

2) The INSTRUMENT REFERENCE INFO catalog object associates a reference with the instrument description. It is repeated for each reference identified for the instrument. A separate REFERENCE template is completed to provide the associated reference citation for each reference.

Include any important references such as instrument description and calibration documents. These can be both published and internal documents or informal memoranda.

The following several pages show an example of a good quality instrument description.

```
PDS_VERSION_ID                            = PDS3
LABEL_REVISION_NOTE                       = "RSIMPSON, 1998-07-01"
RECORD_TYPE                               = STREAM

OBJECT                                    = INSTRUMENT
  INSTRUMENT_HOST_ID                      = "MGN"
  INSTRUMENT_ID                           = "RSS"

  OBJECT                                  = INSTRUMENT_INFORMATION
    INSTRUMENT_NAME                       = "RADIO SCIENCE SUBSYSTEM"
    INSTRUMENT_TYPE                       = "RADIO SCIENCE"
    INSTRUMENT_DESC                       = "


    Instrument Overview
    ===================
      The Magellan Radio Science investigations utilized
      instrumentation with elements on the spacecraft and at the
      DSN.  Much of this is shared equipment, being used for
      routine telecommunications as well as for Radio Science.
      The performance and calibration of both the spacecraft and
      tracking stations directly affect the radio science data
      accuracy, and they play a major role in determining the
      quality of the results.  The spacecraft part of the radio
      science instrument is described immediately below; that is
      followed by a description of the DSN (ground) part of the
      instrument.


    Instrument Specifications - Spacecraft
    ======================================
      The Magellan spacecraft telecommunications subsystem served
      as part of a radio science subsystem for investigations of
      Venus.  Many details of the subsystem are unknown; it's
      'build date' is taken to be 1989-01-01, which was during
      the prelaunch phase of the Magellan mission.

      Instrument Id                  : RSS
      Instrument Host Id             : MGN
      Pi Pds User Id                 : UNK
      Instrument Name                : RADIO SCIENCE SUBSYSTEM
      Instrument Type                : RADIO SCIENCE
      Build Date                     : 1989-01-01
      Instrument Mass                : 102.2 KG
      Instrument Length              : UNK
      Instrument Width               : UNK
      Instrument Height              : UNK
      Instrument Manufacturer Name   : UNK


    Instrument Overview - Spacecraft
    ================================
      The spacecraft radio system was constructed around a
      redundant pair of NASA Standard Transponders (NSTs) which
      received and transmitted at both S-band (2.3 GHz, 13 cm
      wavelength) and X-band (8.4 GHz, 3.6 cm wavelength)
      frequencies.  The exact transmitted frequency was controlled
```

by the signal received from a ground station or by an on-board oscillator. A transponder includes a receiver, command detector, exciter, and low-power amplifier. The transponders provided the usual uplink command and downlink data transmission capabilities.

The spacecraft was capable of either S- or X-band uplink for commanding and simultaneous S- and X-band downlink for telemetry. The NST generated a downlink signal in either a 'coherent' or a 'non-coherent' mode, also known as the 'two-way' and 'one-way' modes, respectively. When operating in the coherent mode, the NST behaved as a conventional transponder; its transmitted carrier frequency was derived coherently from the received uplink carrier frequency with a 'turn-around ratio' of 880/749 at X-band and 240/221 at S-band. When the X-band downlink was controlled by an S-band uplink, the turn-around ratio was (240/221)*(11/3). In the non-coherent mode, the downlink carrier frequency was derived from one of the spacecraft's on-board crystal-controlled oscillators. After a 3-hour warm-up, the crystal oscillator frequency was estimated to be 8425.864 +/- 0.002 MHz at X-band; the S-band signal was lower by a factor 3/11.

The strength of a spacecraft carrier signal, and thus the quality of the radio science data, depends on its modulation state. Magellan radar data were sent to Earth at a nominal rate of 268.8 kilobits per second at X-band; S-band was used for transmission of engineering data at 1.2 kilobits per second. Backup data rates of 115.2 kilobits for radar data and 40 bits per second for engineering were available for special contingencies and were required frequently during later phases of the mission.

Traveling wave tube amplifiers, driven at saturation, amplified the NST output before the signals were radiated via (nominally) a 3.7 m diameter parabolic high gain antenna (HGA). The same antenna was used for the on-board Synthetic Aperture Radar (SAR) system. Medium-gain and low-gain antennas (MGA and LGA, respectively) were also provided.

The S-band signal transmitted by the Magellan HGA was linearly polarized. The X-band signal transmitted by the HGA was circularly polarized, with the sense of polarization depending on the transponder connected.

Science Objectives

Two different types of radio science experiments were conducted with Magellan: radio tracking experiments in which the magnitude and direction of the planet's gravity field were derived from the Doppler (and, sometimes, ranging) measurements, and radio propagation experiments in which modulation on the signal received on Earth could be attributed to properties of the medium. Several variations on the radio propagation experiments were carried out including radio occultations by the atmosphere of Venus and scattering from its surface. Polarization and scintillation measurements were also obtained when the radio wave passed through the solar corona; solar measurements are not covered here.

Gravity Measurements

Measurement of the gravity field provides significant constraints on inferences about interior structure of Venus. Precise, detailed study of the spacecraft motion in Venus orbit can yield the mass distribution of the planet. Topographic data obtained by the Magellan Altimeter (ALT) forms a critical adjunct to these measurements since only after the gravitational effects are adjusted for topography can the gravity anomalies be interpreted geophysically.

Studies of the gravity field emphasize both the global field and local characteristics of the field. The first task is to determine the global field. Doppler and range tracking measurements yield accurate spacecraft trajectory solutions. Simultaneously with reconstruction of the spacecraft orbit, observation equations for field coefficients and a small number of ancillary parameters can be solved. This type of gravity field solution is essential for characterizing tectonic phenomena and can also be used to study localized features.

'Short-arc' line-of-sight Doppler tracking measurements obtained when the Earth-to-spacecraft line-of-sight is within a few degrees of the orbit plane provide the highest resolution of local features. The results from this type of observation typically are presented as contoured acceleration profiles of specific features (e.g., craters, volcanoes, etc.) or line-of-sight acceleration maps of specific regions. The high spatial resolution of these products makes them especially useful to geophysicists for study of features in the size range of 300 to 1,000 km. Because of the relative simplicity of the data analysis, results can be available within a few weeks after the data are collected.

Radio Occultation Measurements

Atmospheric measurements by the method of radio occultation contribute to an improved understanding of structure, circulation, dynamics, and transport in the atmosphere of Venus. These results are based on detailed analysis of the radio signal received from Magellan as it enters and exits occultation by the planet. Two phases of the atmospheric investigation may be defined. The first is to obtain vertical profiles of atmospheric structure with emphasis on investigation of large-scale phenomena. The second is to concentrate on studies of the absorption at various levels in the atmosphere (absorption correlates with concentration of sulfuric acid vapor).

Retrieval of atmospheric profiles requires coherent samples of the radio signal that has propagated through the atmosphere, plus accurate knowledge of the antenna pointing and the spacecraft trajectory. The latter is obtained from the Magellan Navigation Team. Initial solutions from Magellan occultations provided atmospheric structure -- temperature and pressure vs. absolute radius -- to altitudes as low as about 35 km from the surface. The atmosphere becomes critically refracting at levels only a short distance lower, so these results represent very nearly the maximum depth achievable using radio occultation probing.

The spatial and temporal coverage in the radio occultation experiments are determined by the geometry of the spacecraft orbit and the dates and times at which occultation data were acquired. Since radio occultation experiments were conducted on an ad hoc basis, the Magellan coverage is sparse.

Bistatic Surface Scattering Measurements

The spacecraft telecommunications antenna can also be pointed toward the surface of the planet. The strength of the scattered signal from the illuminated area may then be interpreted in terms of the texture of the surface at that point. In an experiment conducted on 6 October 1993, the Magellan high-gain antenna was aimed toward the summit of Gula Mons and the scattered signal was measured at DSN stations in California and Australia. On 9 November 1993, the high-gain antenna was aimed toward the (moving) point on the surface which would give mirror-like reflection toward Earth; those signals were received at the DSN station in Spain. In May and June 1994 experiments were conducted over Maxwell Montes; those data were processed to give the polarization of the reflected signal, which can lead to estimates of complex dielectric constant of the surface material.

Operational Considerations - Spacecraft

Descriptions given here are for nominal performance. The spacecraft transponder system comprised redundant units, each with slightly different characteristics. As transponder units age, their performance changes slightly. More importantly, the performance for radio science depended on operational factors such as the modulation state for the transmitters, which cannot be predicted in advance. The performance also depended on factors which were not always under the control of the Magellan Project. The sample design control table below is adapted from [BUROW1986] for the X-band link carrying 268.8 kbps telemetry. Mean and variance denote expectations after accounting for best and worst case variations on design values.

Parameter	Design Value	Mean	Variance
Transmit Parameters:			
Total transmit power (dBm)	43.42	43.26	0.0139
Transmit circuit loss (dB)	-0.80	-0.85	0.0176
Transmit antenna gain (dB)	48.75	48.75	0.0104
Transmit antenna pointing (dB)	1.03	-0.65	0.1484
Path Parameters:			
Space loss (dB)	-279.09	-279.09	--
Atmospheric loss (dB)	-0.31	-0.31	0.0000
Receive Parameters:			
Polarization loss (dB)	-0.04	-0.04	0.0005
Receive antenna gain (dB)	73.42	73.42	0.1200
Receive antenna pointing (dB)	-0.10	-0.07	0.0006
Receive circuit loss (dB)	0.00	0.00	0.0000
Total Power Summary:			
Net loss (dB)		-158.84	0.2975
Total receiver power (dBm)		-115.58	0.3114
Receiver noise (dBm/Hz)	-179.64	-179.76	0.0416
Carrier Performance:			
Carrier modulation loss (dB)	-13.83	-14.32	2.1302
Polarization loss (dB)	0.00	0.00	0.0000
Receiver carrier power (dBm)		-129.90	2.4416
Carrier noise bandwidth (dB/Hz)	20.00	19.98	0.2111
Carrier threshold SNR (dB)	10.00	10.00	0.0000
Carrier threshold power (dBm)		-149.78	0.0627
Performance margin (dB)		19.98	2.5042

On 4 January 1992 at 15:39 UTC, after a star calibration on orbit 3880, the X-band telemetry and high-rate science data did not reappear in the Magellan downlink. After several configuration changes and diagnostic tests, the Spacecraft Team reached the preliminary conclusion that a summing amplifier in Transponder-A had failed. This summing amplifier combined the X-band engineering and science telemetry signals before phase-modulation, amplification, and transmission of the signal to Earth via the High-Gain Antenna. As part of the testing on 4 January, Transponder-B was turned on and substituted for Transponder-A for about 25 minutes. Transponder-B had been turned off on 13 March 1991 when it developed a spurious sideband that masked the data subcarriers. The spurious signal appeared several MHz above the carrier frequency at X-band, sometimes containing more power than the carrier. During the short test on 4 January, Transponder-B started out at 28-deg C and transmitted good data to Earth. Later it warmed to 34-deg C and the downlink signal degraded. The probable failure mechanism of Transponder-B was determined to be a cracked, failed capacitor. Informal Spacecraft Team contacts with Motorola on 6 January indicated that Transponder-B might be returned to use if it were operated with little or no thermal cycling. That

strategy was adopted for most of the remainder of the mission. Use of the 115.2 kbs science data rate allowed reception of radar data on Earth through most of that time despite presence of the spur, but the mapping time on each orbit was reduced commensurate with the playback capabilities. Both Transponder-A and -B could support gravity observations in their degraded states. Both transponders had strong X-band carriers in spite of their failures. The existence of the spur also affected radio propagation observations to the extent that carrier power was reduced to about half of its nominal level when Transponder-B was in use. Over time periods of an orbit, the frequency and strength of the spur did not change appreciably; so a calibration of carrier level at one point in the orbit was sufficient to establish carrier level during other parts of the orbit.

The table below gives nominal performance. For the bistatic surface scattering observations on 6 Oct 1993, estimates of transmitted power and spur parameters were derived from spacecraft engineering telemetry and ground measurements. The total power at S-band was 4.188+/-0.025 watts; the total power at X-band was 17.298+/-0.100 watts. The X-band spur was approximately 9.3 MHz above and 0.5 dB stronger than the carrier.

Calibration Description - Spacecraft

No information available.

Platform Mounting Descriptions - Spacecraft

The spacecraft +Z axis vector was in the nominal direction of the HGA boresight. The +X axis vector was parallel to the nominal rotation axis of the solar panels. The +Y axis vector formed a right-handed coordinate system and was in the nominal direction of the star scanner boresight. The spacecraft velocity vector was in approximately the -Y direction when the spacecraft was oriented for left-looking SAR operation. The nominal HGA S-band polarization was linear in the y-direction; the nominal X-band polarization was circular, with the sense depending on the transmitter attached.

```
Cone Offset Angle             : 0.00
Cross Cone Offset Angle       : 0.00
Twist Offset Angle            : 0.00
```

The medium gain antenna boresight was 70 degrees from the +Z direction and 20 degrees from the -Y direction. The low gain antenna was mounted on the back of the HGA feed; it's boresight was in the +Z direction and it had a hemispherical radiation pattern.

Principal Investigators

The Principal Investigators for the gravity investigations were William L. Sjogren, Michel Lefebvre, and Georges Balmino. The Principal Investigator for the radio occultation experiments was G. Leonard Tyler. The Principal Investigator for the surface bistatic radar experiments was Gordon H. Pettengill.

Instrument Section / Operating Mode Descriptions - Spacecraft

The Magellan radio system consisted of two sections, which could be operated in the following modes:

Section	Mode
Oscillator	two-way (coherent)
	one-way (non-coherent)
RF output	low-gain antenna (no information available)
	medium-gain antenna
	high-gain antenna

Selected parameters describing NST performance are listed below:

Oscillator Parameters:	S-Band	X-Band
Two-Way Transponder Turnaround Ratio	880/749	880/749
One-Way Transmit Frequency (MHz)	2297.963	8425.864
Frequency Uncertainty (+/- MHz)	0.0005	0.002
Nominal Wavelength (cm)	12.97	3.54

RF Output parameters:	S-Band	X-Band
RF Power Output (w)	5.6	17.8
Medium-Gain Antenna:		
Half-Power Half Beamwidth (deg)	9.2	
Gain (dBi)	19.	
EIRP (dBm)	56.5	
Polarization	Circular	
High-Gain Antenna:		
Half-Power Half-Beamwidth (deg)	1.1	0.32
Gain (dBi)	35.9	48.3
EIRP (dBm)	71.4	90.5
Polarization	Linear	Circular

Instrument Overview - DSN

Three Deep Space Communications Complexes (DSCCs) (near Barstow, CA; Canberra, Australia; and Madrid, Spain) comprise the DSN tracking network. Each complex is equipped with several antennas [including at least one each 70-m, 34-m High Efficiency (HEF), and 34-m standard (STD)], associated electronics, and operational systems. Primary activity at each complex is radiation of commands to and reception of telemetry data from active spacecraft. Transmission and reception is possible in several radio-frequency bands, the most common being S-band (nominally a frequency of 2100-2300 MHz or a wavelength of 14.2-13.0 cm) and X-band (7100-8500 MHz or 4.2-3.5 cm). Transmitter output powers of up to 400 kw are available.

Ground stations have the ability to transmit coded and uncoded waveforms which can be echoed by distant spacecraft. Analysis of the received coding allows navigators to determine the distance to the spacecraft; analysis of Doppler shift on the carrier signal allows estimation of the line-of-sight spacecraft velocity. Range and Doppler measurements are used to calculate the spacecraft trajectory and to infer gravity fields of objects near the spacecraft.

Ground stations can record spacecraft signals that have propagated through or been scattered from target media. Measurements of signal parameters after wave interactions with surfaces, atmospheres, rings, and plasmas are used to infer physical and electrical properties of the target.

Principal investigators vary from experiment to experiment. See the corresponding section of the spacecraft instrument description or the data set description for specifics.

The Deep Space Network is managed by the Jet Propulsion Laboratory of the California Institute of Technology for the U.S. National Aeronautics and Space Administration. Specifications include:

Instrument Id	: RSS
Instrument Host Id	: DSN
Pi Pds User Id	: N/A
Instrument Name	: RADIO SCIENCE SUBSYSTEM
Instrument Type	: RADIO SCIENCE
Build Date	: N/A
Instrument Mass	: N/A
Instrument Length	: N/A
Instrument Width	: N/A
Instrument Height	: N/A
Instrument Manufacturer Name	: N/A

For more information on the Deep Space Network and its use in radio science investigations see the reports by [ASMAR&RENZETTI1993] and [ASMAR&HERRERA1993]. For design specifications on DSN subsystems see [DSN810-5]. For an example of use of the DSN for Radio Science see [TYLERETAL1992].

Subsystems - DSN

The Deep Space Communications Complexes (DSCCs) are an integral part of the Radio Science instrument, along with other receiving stations and the spacecraft Radio Frequency Subsystem. Their system performance directly determines the degree of success of Radio Science investigations, and their system calibration determines the degree of accuracy in the results of the experiments. The following paragraphs describe the functions performed by the individual subsystems of a DSCC. This material has been adapted from [ASMAR&HERRERA1993]; for additional information, consult [DSN810-5].

Each DSCC includes a set of antennas, a Signal Processing Center (SPC), and communication links to the Jet Propulsion Laboratory (JPL). The general configuration is illustrated below; antennas (Deep Space Stations, or DSS -- a term carried over from earlier times when antennas were individually instrumented) are listed in the table.

```
    --------   --------   --------   --------   --------
   | DSS 12 | | DSS 18 | | DSS 14 | | DSS 15 | | DSS 16 |
   |34-m STD| |34-m STD| |  70-m  | |34-m HEF| |  26-m  |
    --------   --------   --------   --------   --------
        |           |     |             |          |
        |           v     v             |          v
        |          ---------            |      ---------
         --------->|GOLDSTONE|<----------     |EARTH/ORB|
                   | SPC  10 |<-------------->|  LINK   |
                   ---------                   ---------
                   |   SPC   |<-------------->|  26-M   |
                   |  COMM   |        ------->|  COMM   |
                    ---------        |         ---------
                       |             |            |
                       v             |            v
       ------      ---------         |         ---------
      | NOCC |<--->|   JPL   |<-------         |         |
       ------      | CENTRAL |                |  GSFC   |
       ------      |   COMM  |                | NASCOMM |
      | MCCC |<--->| TERMINAL|<-------------->|         |
       ------       ---------                  ---------
                                                ^     ^
                                                |     |
             CANBERRA (SPC 40) <-----------------      |
                                                      |
               MADRID (SPC 60) <----------------------
```

Antenna	GOLDSTONE SPC 10	CANBERRA SPC 40	MADRID SPC 60
26-m	DSS 16	DSS 46	DSS 66
34-m STD	DSS 12	DSS 42	DSS 61
	DSS 18	DSS 48	DSS 68
34-m HEF	DSS 15	DSS 45	DSS 65
70-m	DSS 14	DSS 43	DSS 63
Developmental	DSS 13		

Subsystem interconnections at each DSCC are shown in the diagram below, and they are described in the sections that follow. The Monitor and Control Subsystem is connected to all other subsystems; the Test Support Subsystem can be.

```
 ----------   -----------------   ---------   ---------
|TRANSMITTER| |                  | | TRACKING| | COMMAND |
| SUBSYSTEM |-| RECEIVER/EXCITER |-|SUBSYSTEM|-|SUBSYSTEM|-
```

```
 -----------  |                  |  ---------   ---------  |
      |       |     SUBSYSTEM    |       |           |      |
 -----------  |                  |  ---------------------  |
| MICROWAVE | |                  | |      TELEMETRY      | |
| SUBSYSTEM |-|                  |-|      SUBSYSTEM      |-
 -----------   ------------------   ---------------------  |
      |                                                     |
 -----------    -----------    ---------   --------------  |
|  ANTENNA  |  |  MONITOR  |  |   TEST  | |    DIGITAL   | |
| SUBSYSTEM |  |AND CONTROL|  | SUPPORT | |COMMUNICATIONS|-
 -----------   | SUBSYSTEM |  |SUBSYSTEM| |   SUBSYSTEM  |
                -----------    ---------   --------------
```

DSCC Monitor and Control Subsystem

The DSCC Monitor and Control Subsystem (DMC) is part of the Monitor and Control System (MON) which also includes the ground communications Central Communications Terminal and the Network Operations Control Center (NOCC) Monitor and Control Subsystem. The DMC is the center of activity at a DSCC. The DMC receives and archives most of the information from the NOCC needed by the various DSCC subsystems during their operation. Control of most of the DSCC subsystems, as well as the handling and displaying of any responses to control directives and configuration and status information received from each of the subsystems, is done through the DMC. The effect of this is to centralize the control, display, and archiving functions necessary to operate a DSCC. Communication between the various subsystems is done using a Local Area Network (LAN) hooked up to each subsystem via a network interface unit (NIU).

DMC operations are divided into two separate areas: the Complex Monitor and Control (CMC) and the Link Monitor and Control (LMC). The primary purpose of the CMC processor for Radio Science support is to receive and store all predict sets transmitted from NOCC such as Radio Science, antenna pointing, tracking, receiver, and uplink predict sets and then, at a later time, to distribute them to the appropriate subsystems via the LAN. Those predict sets can be stored in the CMC for a maximum of three days under normal conditions. The CMC also receives, processes, and displays event/alarm messages; maintains an operator log; and produces tape labels for the DSP. Assignment and configuration of the LMCs is done through the CMC; to a limited degree the CMC can perform some of the functions performed by the LMC. There are two CMCs (one on-line and one backup) and three LMCs at each DSCC The backup CMC can function as an additional LMC if necessary.

The LMC processor provides the operator interface for monitor and control of a link -- a group of equipment required to support a spacecraft pass. For Radio Science, a link might include the DSCC Spectrum Processing Subsystem (DSP) (which, in turn, can control the SSI), or the Tracking Subsystem. The LMC also maintains an operator log which includes operator directives and subsystem responses. One important Radio Science specific function that the LMC performs is receipt and transmission of the system temperature and signal level data from the PPM for display at the LMC console and for inclusion in Monitor blocks. These blocks are recorded on magnetic tape as well as appearing in the Mission Control and Computing Center (MCCC) displays. The LMC is required to operate without interruption for the duration of the Radio Science data acquisition period.

The Area Routing Assembly (ARA), which is part of the Digital Communications Subsystem, controls all data communication between the stations and JPL. The ARA receives all required data and status messages from the LMC/CMC and can record them to tape as well as transmit them to JPL via data lines. The ARA also receives predicts and other data from JPL and passes them on to the CMC.

DSCC Antenna Mechanical Subsystem

Multi-mission Radio Science activities require support from the 70-m, 34-m HEF, and 34-m STD antenna subnets. The antennas at each DSCC function as large-aperture collectors which, by double reflection, cause the incoming radio frequency (RF) energy to enter the feed horns. The large collecting surface of the antenna focuses the incoming energy onto a subreflector, which is adjustable in both axial and angular position. These adjustments are made to correct for gravitational deformation of the antenna as it moves between zenith and the horizon; the deformation can be as large as 5 cm. The subreflector adjustments optimize the channeling of energy from the primary reflector to the subreflector and then to the feed horns. The 70-m and 34-m HEF antennas have 'shaped' primary and secondary reflectors, with forms that are modified paraboloids. This customization allows more uniform illumination of one reflector by another. The 34-m STD primary reflectors are classical paraboloids, while the subreflectors are standard hyperboloids.

On the 70-m and 34-m STD antennas, the subreflector directs received energy from the antenna onto a dichroic plate, a device which reflects S-band energy to the S-band feed horn and passes X-band energy through to the X-band feed horn. In the 34-m HEF, there is one 'common aperture feed,' which accepts both frequencies without requiring a dichroic plate. RF energy to be transmitted into space by the horns is focused by the reflectors into narrow cylindrical beams, pointed with high precision (either to the dichroic plate or directly to the subreflector) by a series of drive motors and gear trains that can rotate the movable components and their support structures.

The different antennas can be pointed by several means. Two pointing modes commonly used during tracking passes are CONSCAN and 'blind pointing.' With CONSCAN enabled and a closed loop receiver locked to a spacecraft signal, the system tracks the radio source by conically scanning around its position in the sky. Pointing angle adjustments are computed from signal strength information (feedback) supplied by the receiver. In this mode the Antenna Pointing Assembly (APA) generates a circular scan pattern which is sent to the Antenna Control System (ACS). The ACS adds the scan pattern to the corrected pointing angle predicts. Software in the receiver-exciter controller computes the received signal level and sends it to the APA. The correlation of scan position with the received signal level variations allows the APA to compute offset changes which are sent to the ACS. Thus, within the capability of the closed-loop control system, the scan center is pointed precisely at the apparent direction of the spacecraft signal source. An additional function of the APA is to provide antenna position angles and residuals, antenna control mode/status information, and predict-correction parameters to the Area Routing Assembly (ARA) via the LAN, which then sends this information to JPL via the Ground Communications Facility (GCF) for antenna status monitoring.

During periods when excessive signal level dynamics or low received signal levels are expected (e.g., during an occultation experiment), CONSCAN should not be used. Under these conditions, blind pointing (CONSCAN OFF) is used, and pointing angle adjustments are based on a predetermined Systematic Error Correction (SEC) model.

Independent of CONSCAN state, subreflector motion in at least the z-axis may introduce phase variations into the received Radio Science data. For that reason, during certain experiments, the subreflector in the 70-m and 34-m HEFs may be frozen in the z-axis at a position (often based on elevation angle) selected to minimize phase change and signal degradation. This can be done via Operator Control Inputs (OCIs) from the LMC to the Subreflector Controller (SRC) which resides in the alidade room of the antennas. The SRC passes the commands to motors that drive the subreflector to the desired position. Unlike the 70-m and 34-m HEFs which have azimuth-elevation (AZ-EL) drives, the 34-m STD antennas use (hour angle-declination) HA-DEC drives. The same positioning of the subreflector on the 34-m STD does not create the same effect as on the 70-m and 34-m HEFs.

Pointing angles for all three antenna types are computed by the NOCC Support System (NSS) from an ephemeris provided by the flight project. These predicts are received and archived by the CMC. Before each track, they are transferred to the APA, which transforms the direction cosines of the predicts into AZ-EL coordinates for the 70-m and 34-m HEFs or into HA-DEC coordinates for the 34-m STD antennas. The LMC operator then downloads the antenna AZ-EL or HA-DEC predict points to the antenna-mounted ACS computer along with a selected SEC model. The pointing predicts consist of time-tagged AZ-EL or HA-DEC points at selected time intervals along with polynomial coefficients for interpolation between points.

The ACS automatically interpolates the predict points, corrects the pointing predicts for refraction and subreflector position, and adds the proper systematic error correction and any manually entered antenna offsets. The ACS then sends angular position commands for each axis at the rate of one per second. In the 70-m and 34-m HEF, rate commands are generated from the position commands at the servo controller and are subsequently used to steer the antenna. In the 34-m STD antennas motors, rather than servos, are used to steer the antenna; there is no feedback once the 34-m STD has been told where to point.

When not using binary predicts (the routine mode for spacecraft tracking), the antennas can be pointed using 'planetary mode' -- a simpler mode which uses right ascension (RA) and declination (DEC) values. These change very slowly with respect to the celestial frame. Values are provided to the station in text form for manual entry. The ACS quadratically interpolates among three RA and DEC points which are on one-day centers.

A third pointing mode -- sidereal -- is available for tracking radio sources fixed with respect to the celestial frame.

Regardless of the pointing mode being used, a 70-m antenna has a special high-accuracy pointing capability called 'precision' mode. A pointing control loop derives the main AZ-EL pointing servo drive error signals from a two-axis autocollimator mounted on the Intermediate Reference Structure. The autocollimator projects a light beam to a precision mirror mounted on the Master Equatorial drive system, a much smaller structure, independent of the main antenna, which is exactly positioned in HA and DEC with shaft encoders. The autocollimator detects elevation/cross-elevation errors between the two reference surfaces by measuring the angular displacement of the reflected light beam. This error is compensated for in the antenna servo by moving the antenna in the appropriate AZ-EL direction. Pointing accuracies of 0.004 degrees (15 arc seconds) are possible in 'precision' mode. The 'precision' mode is not available on 34-m antennas -- nor is it needed, since their beamwidths are twice as large as on the 70-m antennas.

DSCC Antenna Microwave Subsystem

70-m Antennas: Each 70-m antenna has three feed cones installed in a structure at the center of the main reflector. The feeds are positioned 120 degrees apart on a circle. Selection of the feed is made by rotation of the subreflector. A dichroic mirror assembly, half on the S-band cone and half on the X-band cone, permits simultaneous use of the S- and X-band frequencies. The third cone is devoted to R&D and more specialized work.

The Antenna Microwave Subsystem (AMS) accepts the received S- and X-band signals at the feed horn and transmits them through polarizer plates to an orthomode transducer. The polarizer plates are adjusted so that the signals are directed to a pair of redundant amplifiers for each frequency, thus allowing simultaneous reception of signals in two orthogonal polarizations. For S-band these are two Block IVA S-band Traveling Wave Masers (TWMs); for X-band the amplifiers are Block IIA TWMs.

34-m STD Antennas: These antennas have two feed horns, one for S-band signals and one for X-band. The horns are mounted on a cone which is fixed in relation to the subreflector. A dichroic plate mounted above the horns directs energy from the subreflector into the proper horn.

The AMS directs the received S- and X-band signals through polarizer plates and on to amplification. There are two Block III S-band TWMs and two Block I X-band TWMs.

34-m HEF Antennas: Unlike the other antennas, the 34-m HEF uses a single feed for both S- and X-band. Simultaneous S- and X-band receive as well as X-band transmit is possible thanks to the presence of an S/X 'combiner' which acts as a diplexer. For S-band, RCP or LCP is user selected through a switch so neither a polarizer nor an orthomode transducer is needed. X-band amplification options include two Block II TWMs or an HEMT Low Noise Amplifier (LNA). S-band amplification is provided by an FET LNA.

DSCC Receiver-Exciter Subsystem

The Receiver-Exciter Subsystem is composed of three groups of equipment: the closed-loop receiver group, the open-loop receiver group, and the RF monitor group. This subsystem is controlled by the Receiver-Exciter Controller (REC) which communicates directly with the DMC for predicts and OCI reception and status reporting.

The exciter generates the S-band signal (or X-band for the 34-m HEF only) which is provided to the Transmitter Subsystem for the spacecraft uplink signal. It is tunable under command of the Digitally Controlled Oscillator (DCO) which receives predicts from the Metric Data Assembly (MDA).

The diplexer in the signal path between the transmitter and the feed horn for all three antennas (used for simultaneous transmission and reception) may be configured such that it is out of the received signal path (in listen-only or bypass mode) in order to improve the signal-to-noise ratio in the receiver system.

Closed Loop Receivers: The Block IV receiver-exciter at the 70-m stations allows for two receiver channels, each capable of L-Band (e.g., 1668 MHz frequency or 18 cm wavelength), S-band, or X-band reception, and an S-band exciter for generation of uplink signals through the low-power or high-power transmitter. The Block III receiver-exciter at the 34-m STD stations allows for two receiver channels, each capable of S-band or X-band reception and an exciter used to generate an uplink signal through the low-power transmitter. The receiver-exciter at the 34-m HEF stations allows for one channel only.

The closed-loop receivers provide the capability for rapid acquisition of a spacecraft signal and telemetry lockup. In order to accomplish acquisition within a short time, the receivers are predict driven to search for, acquire, and track the downlink automatically. Rapid acquisition precludes manual tuning though that remains as a backup capability. The subsystem utilizes FFT analyzers for rapid acquisition. The predicts are NSS generated, transmitted to the CMC which sends them to the Receiver-Exciter Subsystem where two sets can be stored. The receiver starts acquisition at uplink time plus one round-trip-light-time or at operator specified times. The receivers may also be operated from the LMC without a local operator attending them. The receivers send performance and status data, displays, and event messages to the LMC.

Either the exciter synthesizer signal or the simulation (SIM) synthesizer signal is used as the reference for the Doppler extractor in the closed-loop receiver systems, depending on the spacecraft being tracked (and Project guidelines). The SIM synthesizer is not ramped; instead it uses one constant frequency, the Track Synthesizer Frequency (TSF), which is an average frequency for the entire pass.

The closed-loop receiver AGC loop can be configured to one of three settings: narrow, medium, or wide. It will be configured such that the expected amplitude changes are accommodated with minimum distortion. The loop bandwidth (2BLo) will be configured such that the expected phase changes can be accommodated while maintaining the best possible loop SNR.

Open-Loop Receivers: The Radio Science Open-Loop Receiver (OLR) is a dedicated four channel, narrow-band receiver which provides amplified and downconverted video band signals to the DSCC Spectrum Processing Subsystem (DSP).

The OLR utilizes a fixed first Local Oscillator (LO) frequency and a tunable second LO frequency to minimize phase noise and improve frequency stability. The OLR consists of an RF-to-IF downconverter located in the antenna, an IF selection switch (IVC), and a Radio Science IF-VF downconverter (RIV) located in the SPC. The RF-IF downconverters in the 70-m antennas are equipped for four IF channels: S-RCP, S-LCP, X-RCP, and X-LCP. The 34-m HEF stations are equipped with a two-channel RF-IF: S-band and X-band. The IVC switches the IF input between the 70-m and 34-m HEF antennas.

The RIV contains the tunable second LO, a set of video bandpass filters, IF attenuators, and a controller (RIC). The LO tuning is done via DSP control of the POCA/PLO combination based on a predict set. The POCA is a Programmable Oscillator Control Assembly and the PLO is a Programmable Local Oscillator (commonly called the DANA synthesizer). The bandpass filters are selectable via the DSP. The RIC provides an interface between the DSP and the RIV. It is controlled from the LMC via the DSP. The RIC selects the filter and attenuator settings and provides monitor data to the DSP. The RIC could also be manually controlled from the front panel in case the electronic interface to the DSP is lost.

RF Monitor -- SSI and PPM: The RF monitor group of the Receiver-Exciter Subsystem provides spectral measurements using the Spectral Signal Indicator (SSI) and measurements of the received channel system temperature and spacecraft signal level using the Precision Power Monitor (PPM).

The SSI provides a local display of the received signal spectrum at a dedicated terminal at the DSCC and routes these same data to the DSP which routes them to NOCC for remote display at JPL for real-time monitoring and RIV/DSP configuration verification. These displays are used to validate Radio Science Subsystem data at the DSS, NOCC, and Mission Support Areas. The SSI configuration is controlled by the DSP and a duplicate of the SSI spectrum appears on the LMC via the DSP. During real-time operations the SSI data also serve as a quick-look science data type for Radio Science experiments.

The PPM measures system noise temperatures (SNT) using a Noise Adding Radiometer (NAR) and downlink signal levels using the Signal Level Estimator (SLE). The PPM accepts its input from the closed-loop receiver. The SNT is measured by injecting known amounts of noise power into the signal path and comparing the total power with the noise injection 'on' against the total power with the noise injection 'off.' That operation is based on the fact that receiver noise power is directly proportional to temperature; thus measuring the relative increase in noise power due to the presence of a calibrated thermal noise source allows direct calculation of SNT. Signal level is measured by calculating an FFT to estimate the SNR between the signal level and the receiver noise floor where the power is known from the SNT measurements.

There is one PPM controller at the SPC which is used to control all SNT measurements. The SNT integration time can be selected to represent the time required for a measurement of 30K to have a one-sigma uncertainty of 0.3K or 1%.

DSCC Transmitter Subsystem

The Transmitter Subsystem accepts the S-band frequency exciter signal from the Block III or Block IV Receiver-Exciter Subsystem exciter and amplifies it to the required transmit output level. The amplified signal is routed via the diplexer through the feed horn to the antenna and then focused and beamed to the spacecraft.

The Transmitter Subsystem power capabilities range from 18 kw to 400 kw. Power levels above 18 kw are available only at 70-m stations.

DSCC Tracking Subsystem

The Tracking Subsystem primary functions are to acquire and maintain communications with the spacecraft and to generate and format radiometric data containing Doppler and range.

The DSCC Tracking Subsystem (DTK) receives the carrier signals and ranging spectra from the Receiver-Exciter Subsystem. The Doppler cycle counts are counted, formatted, and transmitted to JPL in real time. Ranging data are also transmitted to JPL in real time. Also contained in these blocks is the AGC information from the Receiver-Exciter Subsystem. The Radio Metric Data Conditioning Team (RMDCT) at JPL produces an Archival Tracking Data File (ATDF) tape which contains Doppler and ranging data.

In addition, the Tracking Subsystem receives from the CMC frequency predicts (used to compute frequency residuals and noise estimates), receiver tuning predicts (used to tune the closed-loop receivers), and uplink tuning predicts (used to tune the exciter). From the LMC, it receives configuration and control directives as well as configuration and status information on the transmitter, microwave, and frequency and timing subsystems.

The Metric Data Assembly (MDA) controls all of the DTK functions supporting the uplink and downlink activities. The MDA receives uplink predicts and controls the uplink tuning by commanding the DCO. The MDA also controls the Sequential Ranging Assembly (SRA). It formats the Doppler and range measurements and provides them to the GCF for transmission to NOCC.

The Sequential Ranging Assembly (SRA) measures the round trip light time (RTLT) of a radio signal traveling from a ground tracking station to a spacecraft and back. From the RTLT, phase, and Doppler data, the spacecraft range can be determined. A coded signal is modulated on an uplink carrier and transmitted to the spacecraft where it is detected and transponded back to the ground station. As a result, the signal received at the tracking station is delayed by its round trip through space and shifted in frequency by the Doppler effect due to the relative motion between the spacecraft and the tracking station on Earth.

DSCC Spectrum Processing Subsystem (DSP)

The DSCC Spectrum Processing Subsystem (DSP) located at the SPC digitizes and records on magnetic tapes the narrowband output data from the RIV. It consists of a Narrow Band Occultation Converter (NBOC) containing four Analog-to-Digital Converters (ADCs), a ModComp CLASSIC computer processor called the Spectrum Processing Assembly (SPA), and two to six magnetic tape drives. Magnetic tapes are known as Original Data Records (ODRs). Electronic near real-time transmission of data to JPL (an Original Data Stream, or ODS) may be possible in certain circumstances;

The DSP is operated through the LMC. Using the SPA-R software, the DSP allows for real-time frequency and time offsets (while in RUN mode) and, if necessary, snap tuning between the two frequency ranges transmitted by the spacecraft: coherent and non-coherent. The DSP receives Radio Science frequency predicts from the CMC, allows for multiple predict set archiving (up to 60 sets) at the SPA, and allows for manual predict generation and editing. It accepts configuration and control data from the LMC, provides display data to the LMC, and transmits the signal spectra from the SSI as well as status information to NOCC and the Project Mission Support Area (MSA) via the GCF data lines. The DSP records the digitized narrowband samples and the supporting header information (i.e., time tags, POCA frequencies, etc.) on 9-track magnetic tapes in 6250 or 1600 bpi GCR format.

Through the DSP-RIC interface the DSP controls the RIV filter selection and attenuation levels. It also receives RIV performance monitoring via the RIC. In case of failure of the DSP-RIC interface, the RIV can be controlled manually from the front panel.

All the RIV and DSP control parameters and configuration directives are stored in the SPA in a macro-like file called an 'experiment directive' table. A number of default directives exist in the DSP for the major Radio Science experiments. Operators can create their own table entries.

Items such as verification of the configuration of the prime open-loop recording subsystem, the selection of the required predict sets, and proper system performance prior to the recording periods will be checked in real-time at JPL via the NOCC displays using primarily the remote SSI display at NOCC and the NRV displays. Because of this, transmission of the DSP/SSI monitor information is enabled prior to the start of recording. The specific run time and tape recording times will be identified in the Sequence of Events (SOE) and/or DSN Keyword File.

The DSP can be used to duplicate ODRs. It also has the capability to play back a certain section of the recorded data after conclusion of the recording periods.

DSCC Frequency and Timing Subsystem

The Frequency and Timing Subsystem (FTS) provides all frequency and timing references required by the other DSCC subsystems. It contains four frequency standards of which one is prime and the other three are backups. Selection of the prime standard is done via the CMC. Of these four standards, two are hydrogen masers followed by clean-up loops (CUL) and two are cesium standards. These four standards all feed the Coherent Reference Generator (CRG) which provides the frequency references used by the rest of the complex. It also provides the frequency reference to the Master Clock Assembly (MCA) which in turn provides time to the Time Insertion and Distribution Assembly (TID) which provides UTC and SIM-time to the complex.

JPL's ability to monitor the FTS at each DSCC is limited to the MDA calculated Doppler pseudo-residuals, the Doppler noise, the SSI, and to a system which uses the Global Positioning System (GPS). GPS receivers at each DSCC receive a one-pulse-per-second pulse from the station's (hydrogen maser referenced) FTS and a pulse from a GPS satellite at scheduled times. After compensating for the satellite signal delay, the timing offset is reported to JPL where a database is kept. The clock offsets stored in the JPL database are given in microseconds; each entry is a mean reading of measurements from several GPS satellites and a time tag associated with the mean reading. The clock offsets provided include those of SPC 10 relative to UTC (NIST), SPC 40 relative to SPC 10, etc.

Optics - DSN

Performance of DSN ground stations depends primarily on size of the antenna and capabilities of electronics. These are summarized in the following set of tables. Note that 64-m antennas were upgraded to 70-m between 1986 and 1989. Beamwidth is half-power full angular width. Polarization is circular; L denotes left circular polarization (LCP), and R denotes right circular polarization (RCP).

DSS S-Band Characteristics

Transmit	64-m	70-m	34-m STD	34-m HEF
Frequency (MHz)	2110-2120	2110-2120	2025-2120	N/A
Wavelength (m)	0.142	0.142	0.142	N/A
Ant Gain (dBi)		62.7	55.2	N/A
Beamwidth (deg)		0.119	0.31	N/A
Polarization		L or R	L or R	N/A
Tx Power (kW)		20-400	20	N/A

Receive

Receive	64-m	70-m	34-m STD	34-m HEF
Frequency (MHz)	2270-2300	2270-2300	2270-2300	2200-2300
Wavelength (m)	0.131	0.131	0.131	0.131
Ant Gain (dBi)	61.6	63.3	56.2	56.0
Beamwidth (deg)		0.108	0.27	0.24
Polarization	L & R	L & R	L or R	L or R
System Temp (K)	22	20	22	38

DSS X-Band Characteristics

Transmit	64-m	70-m	34-m STD	34-m HEF
Frequency (MHz)	8495	8495	N/A	7145-7190
Wavelength (m)	0.035	0.035	N/A	0.042
Ant Gain (dBi)		74.2	N/A	67
Beamwidth (deg)			N/A	0.074
Polarization	L or R	L or R	N/A	L or R
Tx Power (kW)	360	360	N/A	20

Receive	64-m	70-m	34-m STD	34-m HEF
Frequency (MHz)	8400-8500	8400-8500	8400-8500	8400-8500
Wavelength (m)	0.036	0.036	0.036	0.036
Ant Gain (dBi)	71.7	74.2	66.2	68.3
Beamwidth (deg)		0.031	0.075	0.063
Polarization	L & R	L & R	L & R	L & R
System Temp (K)	27	20	25	20

Electronics - DSN

DSCC Open-Loop Receiver

The open loop receiver block diagram shown below is for 70-m and 34-m High-Efficiency (HEF) antenna sites. Based on a tuning prediction file, the POCA controls the DANA synthesizer the output of which (after multiplication) mixes input signals at both S- and X-band to fixed intermediate frequencies for amplification. These signals in turn are down converted and passed through additional filters until they yield baseband output of up to 25 kHz in width. The baseband output is digitally sampled by the DSP and either written to magnetic tape or electronically transferred for further analysis.

```
 S-Band                                                X-Band
2295 MHz                                              8415 MHz
 Input                                                 Input
   |                                                     |
   v                                                     v
  ---     ---                                 ---     ---
 | X |<--|x20|<--100 MHz        100 MHz-->|x81|-->| X |
```

```
   ---     ---                              ---     ---
    |                                                |
 295|                                                |315
 MHz|                                                |MHz
    v                                                v
   ---     --                 33.1818       ---     ---
  | X |<--|x3|<------           MHz ------>|x11|-->| X |
   ---     --        |115          |        ---     ---
    |                |MHz          |                 |
    |                |             |                 |
  50|      71.8181  ---           ---                |50
 MHz|         MHz->| X |         | X |<-10MHz        |MHz
    v               ---           ---                v
   ---               ^             ^                ---
  | X |<--60 MHz     |             |      60 MHz-->| X |
   ---               |             |                ---
    |        9.9     | 43.1818 MHz |      9.9        |
    |        MHz      -------------       MHz        |
    |         |             ^              |         |
  10|         v             |              v         |10
 MHz|        ---       ----------         ---        |MHz
    |------>| X |     |   DANA   |       | X |<------|
    |        ---      |Synthesizr|        ---        |
    |         |        ----------          |         |
    v         v             ^              v         v
 -------   -------          |           -------   -------
|Filters| |Filters|    ----------      |Filters| |Filters|
|3,4,5,6| |  1,2  |   |   POCA   |     |  1,2  | |3,4,5,6|
 -------   -------    |Controller|      -------   -------
    |         |        ----------          |         |
  10|         |0.1                      0.1|         |10
 MHz|         |MHz                      MHz|         |MHz
    v         v                            v         v
   ---       ---                          ---       ---
  | X |-   -| X |                        | X |-   -| X |
   ---  | |  ---                          ---  | |  ---
    ^   | |   ^                            ^   | |   ^
    |   | |   |                            |   | |   |
   10   | |  0.1                          0.1  | |   10
   MHz  | |  MHz                          MHz  | |  MHz
        | |                                    | |
        v v                                    v v
      Baseband                               Baseband
       Output                                 Output
```

Reconstruction of the antenna frequency from the frequency of the signal in the recorded data can be achieved through use of one of the following formulas.

Radio Science IF-VF (RIV) Converter Assembly at 70-m and 34-m High-Efficiency (HEF) antennas:

```
FSant=3*[POCA+(790/11)*10^6] + 1.95*10^9 - Fsamp - Frec

FXant=11*[POCA-10^7] + 8.050*10^9 - 3*Fsamp + Frec
```

Multi-Mission Receivers at 34-m Standard antennas (DSS 42 and 61; the diagram above does not apply):

FSant=48*POCA + 3*10^8 - 0.75*Fsamp + Frec

FXant = (11/3)*[48*POCA + 3*10^8 - 0.75*Fsamp] + Frec

where
- FSant = S-band antenna frequency
- FXant = X-band antenna frequency
- POCA = POCA frequency
- Fsamp = sampling frequency
- Frec = frequency of recorded signal

Filters - DSN

DSCC Open-Loop Receiver

Nominal filter center frequencies and bandwidths for the Open-Loop Receivers are shown in the table below.

Filter	Center Frequency	3 dB Bandwidth
1	0.1 MHz	90 Hz
2	0.1 MHz	450 Hz
3	10.0 MHz	2000 Hz
4	10.0 MHz	1700 Hz (S-band)
		6250 Hz (X-band)
5	10.0 MHz	45000 Hz
6	10.0 MHz	21000 Hz

MMR filters (DSS 42 and 61) include the following:

Filter	Center Frequency	3 dB Bandwidth
5	Unknown	2045 Hz (S-band)
		7500 Hz (X-band)

Detectors - DSN

DSCC Open-Loop Receivers

Open-loop receiver output is detected in software by the radio science investigator.

DSCC Closed-Loop Receivers

Nominal carrier tracking loop threshold noise bandwidth at both S- and X-band is 10 Hz. Coherent (two-way) closed-loop system stability is shown in the table below:

integration time (secs)	Doppler uncertainty (one sigma, microns/sec)

10	50
60	20
1000	4

Calibration - DSN

Calibrations of hardware systems are carried out periodically by DSN personnel; these ensure that systems operate at required performance levels -- for example, that antenna patterns, receiver gain, propagation delays, and Doppler uncertainties meet specifications. No information on specific calibration activities is available. Nominal performance specifications are shown in the tables above. Additional information may be available in [DSN810-5].

Prior to each tracking pass, station operators perform a series of calibrations to ensure that systems meet specifications for that operational period. Included in these calibrations is measurement of receiver system temperature in the configuration to be employed during the pass. Results of these calibrations are recorded in (hard copy) Controller's Logs for each pass.

The nominal procedure for initializing open-loop receiver attenuator settings is described below. In cases where widely varying signal levels are expected, the procedure may be modified in advance or real-time adjustments may be made to attenuator settings.

Open-Loop Receiver Attenuation Calibration

The open-loop receiver attenuator calibrations are performed to establish the output of the open-loop receivers at a level that will not saturate the analog-to-digital converters. To achieve this, the calibration is done using a test signal generated by the exciter/translator that is set to the peak predicted signal level for the upcoming pass. Then the output level of the receiver's video band spectrum envelope is adjusted to the level determined by equation (3) below (to five-sigma). Note that the SNR in the equation (2) is in dB while the SNR in equation (3) is linear.

```
Pn = -198.6 + 10*log(SNT) + 10*log(1.2*Fbw)              (1)

SNR = Ps - Pn                                (SNR in dB)  (2)

Vrms = sqrt(SNR + 1)/[1 + 0.283*sqrt(SNR)]  (SNR linear) (3)

where    Fbw = receiver filter bandwidth (Hz)
         Pn  = receiver noise power (dBm)
         Ps  = signal power (dBm)
         SNT = system noise temperature (K)
         SNR = predicted signal-to-noise ratio
```

Operational Considerations - DSN

The DSN is a complex and dynamic 'instrument.' Its performance for Radio Science depends on a number of factors from equipment configuration to meteorological conditions. No specific information on 'operational considerations' can be given here.

Operational Modes - DSN

DSCC Antenna Mechanical Subsystem

Pointing of DSCC antennas may be carried out in several ways. For details see the subsection 'DSCC Antenna Mechanical Subsystem' in the 'Subsystem' section. Binary pointing is the preferred mode for tracking spacecraft; pointing predicts are provided, and the antenna simply follows those. With CONSCAN, the antenna scans conically about the optimum pointing direction, using closed-loop receiver signal strength estimates as feedback. In planetary mode, the system interpolates from three (slowly changing) RA-DEC target coordinates; this is 'blind' pointing since there is no feedback from a detected signal. In sidereal mode, the antenna tracks a fixed point on the celestial sphere. In 'precision' mode, the antenna pointing is adjusted using an optical feedback system. It is possible on most antennas to freeze z-axis motion of the subreflector to minimize phase changes in the received signal.

DSCC Receiver-Exciter Subsystem

The diplexer in the signal path between the transmitter and the feed horns on all three antennas may be configured so that it is out of the received signal path in order to improve the signal-to-noise ratio in the receiver system. This is known as the 'listen-only' or 'bypass' mode.

Closed-Loop vs. Open-Loop Reception

Radio Science data can be collected in two modes: closed-loop, in which a phase-locked loop receiver tracks the spacecraft signal, or open-loop, in which a receiver samples and records a band within which the desired signal presumably resides. Closed-loop data are collected using Closed-Loop Receivers, and open-loop data are collected using Open-Loop Receivers in conjunction with the DSCC Spectrum Processing Subsystem (DSP). See the Subsystems section for further information.

Closed-Loop Receiver AGC Loop

The closed-loop receiver AGC loop can be configured to one of three settings: narrow, medium, or wide. Ordinarily it is configured so that expected signal amplitude changes are accommodated with minimum distortion. The loop bandwidth is ordinarily configured so that expected phase changes can be accommodated while maintaining the best possible loop SNR.

Coherent vs. Non-Coherent Operation

The frequency of the signal transmitted from the spacecraft can generally be controlled in two ways -- by locking to a signal received from a ground station or by locking to an on-board oscillator. These are known as the coherent (or 'two-way') and non-coherent ('one-way') modes, respectively. Mode selection is made at the spacecraft, based on commands received from the ground. When operating in the coherent mode, the transponder carrier frequency is derived from the received uplink carrier frequency with a 'turn-around ratio' typically of 240/221. In the non-coherent mode, the downlink carrier frequency is derived from the spacecraft on-board crystal-controlled oscillator. Either closed-loop or open-loop receivers (or both) can be used with either spacecraft frequency reference mode. Closed-loop reception in two-way mode is usually preferred for routine tracking. Occasionally the spacecraft operates coherently while two ground stations receive the 'downlink' signal; this is sometimes known as the 'three-way' mode.

DSCC Spectrum Processing Subsystem (DSP)

The DSP can operate in four sampling modes with from 1 to 4 input signals. Input channels are assigned to ADC inputs during DSP configuration. Modes and sampling rates are summarized in the tables below:

Mode	Analog-to-Digital Operation
1	4 signals, each sampled by a single ADC
2	1 signal, sampled sequentially by 4 ADCs
3	2 signals, each sampled sequentially by 2 ADCs
4	2 signals, the first sampled by ADC #1 and the second sampled sequentially at 3 times the rate by ADCs #2-4

8-bit Samples Sampling Rates (samples/sec per ADC)	12-bit Samples Sampling Rates (samples/sec per ADC)
50000	
31250	
25000	
15625	
12500	
10000	10000
6250	
5000	5000
4000	

3125	
2500	
	2000
1250	
1000	1000
500	
400	
250	
200	200

Location - DSN

Station locations are documented in [GEO-10REVD]. Geocentric coordinates are summarized here.

Station	Geocentric Radius (km)	Geocentric Latitude (N)	Geocentric Longitude (E)
Goldstone			
DSS 12 (34-m STD)	6371.997815	35.1186672	243.1945048
DSS 13 (develop)	6372.117062	35.0665485	243.2051077
DSS 14 (70-m)	6371.992867	35.2443514.	243.1104584
DSS 15 (34-m HEF)	6371.9463	35.2402863	243.1128186
DSS 16 (26-m)	6371.9608	35.1601436	243.1264200
DSS 18 (34-m STD)	UNK	UNK	UNK
Canberra			
DSS 42 (34-m STD)	6371.675607	-35.2191850	148.9812546
DSS 43 (70-m)	6371.688953	-35.2209308	148.9812540
DSS 45 (34-m HEF)	6371.692	-35.21709	148.97757
DSS 46 (26-m)	6371/675	-35.22360	148.98297
DSS 48 (34-m STD)	UNK	UNK	UNK
Madrid			
DSS 61 (34-m STD)	6370.027734	40.2388805	355.7509634
DSS 63 (70-m)	6370.051015	40.2413495	355.7519776
DSS 65 (34-m HEF)	6370.021370	40.2372843	355.7485968
DSS 66 (26-m)	6370.036	40.2400714	355.7485976
DSS 48 (34-m STD)	UNK	UNK	UNK

Measurement Parameters - DSN

Open-Loop System

Output from the Open-Loop Receivers (OLRs), as sampled and recorded by the DSCC Spectrum Processing Subsystem (DSP), is a stream of 8- or 12-bit quantized voltage samples. The nominal input to the Analog-to-Digital Converters (ADCs) is +/-10 volts, but the precise scaling between input voltages and output digitized samples is usually irrelevant for analysis; the digital data are generally referenced to a known noise or signal level within the data stream itself -- for example, the thermal noise output of the radio receivers which has a known system noise temperature (SNT). Raw samples comprise the data block in each DSP record; a header record (presently 83 16-bit words) contains ancillary information such as:

time tag for the first sample in the data block
RMS values of receiver signal levels and ADC outputs
POCA frequency and drift rate

Closed-Loop System

Closed-loop data are recorded in Archival Tracking Data Files (ATDFs), as well as certain secondary products such as the Orbit Data File (ODF). The ATDF Tracking Logical Record contains 117 entries including status information and measurements of ranging, Doppler, and signal strength.

ACRONYMS AND ABBREVIATIONS - DSN

ACS	Antenna Control System
ADC	Analog-to-Digital Converter
AMS	Antenna Microwave System
APA	Antenna Pointing Assembly
ARA	Area Routing Assembly
ATDF	Archival Tracking Data File
AZ	Azimuth
CMC	Complex Monitor and Control
CONSCAN	Conical Scanning (antenna pointing mode)
CRG	Coherent Reference Generator
CUL	Clean-up Loop
DANA	a type of frequency synthesizer
dB	deciBel
dBi	dB relative to isotropic
DCO	Digitally Controlled Oscillator
DEC	Declination
deg	degree
DMC	DSCC Monitor and Control Subsystem
DSCC	Deep Space Communications Complex
DSN	Deep Space Network
DSP	DSCC Spectrum Processing Subsystem
DSS	Deep Space Station
DTK	DSCC Tracking Subsystem
E	east
EL	Elevation
FTS	Frequency and Timing Subsystem
GCF	Ground Communications Facility
GPS	Global Positioning System
HA	Hour Angle
HEF	High-Efficiency (as in 34-m HEF antennas)
IF	Intermediate Frequency
IVC	IF Selection Switch
JPL	Jet Propulsion Laboratory
K	Kelvin
km	kilometer
kW	kilowatt
L-band	approximately 1668 MHz

```
     LAN      Local Area Network
     LCP      Left-Circularly Polarized
     LMC      Link Monitor and Control
     LNA      Low-Noise Amplifier
     LO       Local Oscillator
     m        meters
     MCA      Master Clock Assembly
     MCCC     Mission Control and Computing Center
     MDA      Metric Data Assembly
     MHz      Megahertz
     MON      Monitor and Control System
     MSA      Mission Support Area
     N        north
     NAR      Noise Adding Radiometer
     NBOC     Narrow-Band Occultation Converter
     NIST     SPC 10 time relative to UTC
     NIU      Network Interface Unit
     NOCC     Network Operations and Control System
     NSS      NOCC Support System
     OCI      Operator Control Input
     ODF      Orbit Data File
     ODR      Original Data Record
     ODS      Original Data Stream
     OLR      Open Loop Receiver
     POCA     Programmable Oscillator Control Assembly
     PPM      Precision Power Monitor
     RA       Right Ascension
     REC      Receiver-Exciter Controller
     RCP      Right-Circularly Polarized
     RF       Radio Frequency
     RIC      RIV Controller
     RIV      Radio Science IF-VF Converter Assembly
     RMDCT    Radio Metric Data Conditioning Team
     RTLT     Round-Trip Light Time
     S-band   approximately 2100-2300 MHz
     sec      second
     SEC      System Error Correction
     SIM      Simulation
     SLE      Signal Level Estimator
     SNR      Signal-to-Noise Ratio
     SNT      System Noise Temperature
     SOE      Sequence of Events
     SPA      Spectrum Processing Assembly
     SPC      Signal Processing Center
     SRA      Sequential Ranging Assembly
     SRC      Sub-Reflector Controller
     SSI      Spectral Signal Indicator
     STD      Standard (as in 34-m STD antennas)
     TID      Time Insertion and Distribution Assembly
     TSF      Tracking Synthesizer Frequency
     TWM      Traveling Wave Maser
     UNK      unknown
     UTC      Universal Coordinated Time
     VF       Video Frequency
     X-band   approximately 7800-8500 MHz
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